LIMNOLOGICAL INVESTIGATION OF

GIL LAKE, KUIU ISLAND, SOUTHEAST ALASKA, 1997

by
Renate Riffe
and
Margaret Cartwright

Regional Information Report[1] No. 1J02-42

A final project report to the U.S. Forest Service
to fulfill obligations for Sikes Act Contract
Number 43-0112-7-0026

Alaska Department of Fish and Game
Division of Commercial Fisheries
P.O. Box 240020
Douglas, Alaska 99824-0020

November 2002

[1] The Regional Information Report Series was established in 1987 to provide an information access system for all unpublished divisional reports. These reports frequently serve diverse ad hoc informational purposes or archive basic uninterpreted data. To accommodate timely reporting of recently collected information, reports in this series undergo only limited internal review and may contain preliminary data, this information may be subsequently finalized and published in the formal literature. Consequently, these reports should not be cited without prior approval of the author or the Division of Commercial Fisheries.

AUTHORS

Renate Riffe is a fishery biologist for the Alaska Department of Fish and Game, Division of Commercial Fisheries, Island Center Building, 802 Third Street, Douglas, Alaska 99824-0020

Margaret Cartwright is a fishery biologist for the Alaska Department of Fish and Game, Division of Commercial Fisheries, Island Center Building, 802 Third Street, Douglas, Alaska 99824-0020

ACKNOWLEDGEMENTS

The authors wish to thank Dave Barto, who collected and compiled the data, and Hal Geiger for his guidance in writing this report. Thanks also to the biologists and technicians at the limnology lab in Soldotna, who process and analyze samples at the highest standards.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The Alaska Department of Fish and Game, Division of Commercial Fisheries, initiated a one-year limnological study of Gil Lake during 1997, under a cooperative agreement with the U.S. Forest Service, to determine if the productivity of lake could support an adequate sockeye salmon (*Oncorhynchus nerka*) fry population. The intent was to investigate the possibility of developing a terminal gillnet subsistence fishery in marine waters near the outlet stream of Gil Lake. Surface area of the lake is 40 hectares, and the mean and maximum depths are 8 meters and 28 meters, respectively. The seasonal mean euphotic zone was 5.1 meters deep. All water quality values were within ranges normally seen in coastal Alaskan oligotrophic lakes. No potential spawning areas in inlet streams or in the lake were observed during the study, which would rule out the option of constructing a fish pass and developing a self-sustaining sockeye salmon run. The Gil Lake zooplankton density and biomass were near the median for coastal Alaskan lakes, but was low for barriered systems that contained no sockeye salmon. Consequently, the Gil Lake zooplankton biomass will drop even lower if sockeye salmon fry are stocked into the lake. Therefore, lake fertilization will most likely be required to provide a sufficient food base for the stocked sockeye salmon fry. Stocking sockeye salmon fry after the addition of nutrients would require constant monitoring of the balance between production at low levels and consumption at higher trophic levels, a feat that has not always been successful. Although an enhancement project to create a subsistence terminal fishery is possible in the Gil Lake area, the cost and time to boost lake primary production to a level that could support a population of sockeye salmon fry, the unknown success of stocking and rearing fry, and the inability to develop a self-sustained run does not make it a good candidate for enhancement.

INTRODUCTION

Gil Lake has an outlet stream with significant outlet falls, which prevents anadromous fish from entering to the system. The Organized Village of Kake (OVK), U.S. Forest Service (USFS), and the Alaska Department of Fish and Game (ADF&G) expressed interest in introducing Pacific salmon into the watershed. In 1986, USFS considered constructing a fish passage for coho salmon (*Onchorhynchus kisutch*), but shelved the idea because of limited stream habitat (Robert Larsen, USFS, Petersburg, Alaska, pers. comm.). The USFS proposed developing a sockeye salmon gillnet subsistence fishery in the terminal area in marine waters near the outlet of Gil Lake. Because of the lack of spawning habitat for sockeye salmon, this project proposed stocking sockeye salmon fry in the lake annually for a terminal fishery. At present, Kake residents travel across Chatham Strait to Falls Lake to subsistence fish for sockeye salmon. Gil Lake is much closer to the village and Keku Strait is more protected and narrower than Chatham Strait. In 1997, the U.S. Forest Service contracted the ADF&G, Division of Commercial Fisheries to conduct a limnological study of Gil Lake for one year. The goal of the study was to determine the lake's rearing capacity for sockeye juveniles and smolts. This paper reports the results of the limnology information collected in Gil Lake in 1997.

Study Site Description

Gil Lake (134°5' W. long., 56°53' N. lat.) is a stained lake, located approximately 71 kilometers (44 miles) west of Petersburg on northern Kuiu Island, and lies within the Tongass National Forest. Gil Lake (ADF&G stream no. 109-42-040) is at an elevation of 77 meters (252 feet), and has an approximate surface area of 40 hectares (100 acres) and a maximum depth of 28 meters (92 feet). Forest road 46092 is located approximately 0.5 kilometers (1/4 mile) north of the lake. USFS personnel surveyed the lake to identify resident fish species. At the time of this report this information was not available.

MATERIALS AND METHODS

Field Surveys and Sampling

Lake-depth measurements were collected, using a Simrad EY-M sonar unit with a strip chart recorder to create a bathymetric map of Gil Lake. A variable number of transects were run orthogonally across the lake to achieve representative sampling of the bottom contours. The boat was operated at a constant speed and several of the transects were run from one prominent point to another.

Limnology sampling occurred once each month during the ice-free (May to October) portion of the year at two permanent sampling sites in Gil Lake (Figure 1). Data were collected and analyzed according to standards specified by the ADF&G limnology laboratory (Koenings et al. 1987). At site 1, all types of data were collected, including physical, chemical, and biological production data. Only zooplankton samples were collected at site 1B. Measurements of light intensity were recorded at varying intervals using a Protomatic analog submarine photometer. The photometer sensor was held above the surface of the water to determine the incident light levels, then held 5 cm below the surface of the water for maximum subsurface incident light level, and then lowered by 1-meter increments until a reading of 1% of incident subsurface (5 cm) light was achieved. Dissolved oxygen and temperature readings were taken using a YSI model 57 meter. The meter was calibrated for dissolved oxygen in the field by setting the 1 meter dissolved oxygen level to the same reading measured using a Winkler titration. A YSI model 33 was used to measure conductivity. Bulk (~5 L) water samples were taken from one site (Site 1), at 1m and 13 m depth strata, and the results were used to characterize the epilimnion and hypolimnion. Primary production (algal standing crop) samples were collected, concurrent with the water samples collected for nutrient analysis. Sampling occurred during each of these periods at 1 m, mid-euphotic zone, and at the compensation depth, defined as the depth penetrated by 1% of sub-surface sunlight.

Replicated vertical zooplankton tows were collected from a depth of 15 m from the main sampling site (Site 1) and from 9 or 10 m at the secondary site (Site 1B). These vertical tows were collected using a 0.5 meter diameter, 153 μ mesh, 1:3 conical zooplankton net. The net was retrieved at a constant rate of ~ 1 m/sec., rinsed with lake water to remove all of the organisms collected, and the concentrated samples preserved in a solution of 10% neutralized formalin.

Laboratory Analysis

Lake surface area (A_L) was determined from orthographic aerial photographs obtained from USFS and ArcView© graphical software package. Drainage area (A_P) was computed from topographic maps using a polar planimeter. Transects recorded in the field were transferred to an outline of Gil Lake and scaled using a topographic map of the lake. Contour lines were drawn every X meters. Following the creation of a bathymetric map, the area of component depth strata, volume by depth strata, and total lake volume (V) was determined using ArcView© graphical software package.

Mean depth, total lake overflow, and theoretical water residence time were calculated after Hutchinson (1957). Let V equal lake volume in cubic meters, and A_L equal lake area in square meters. Mean depth Z is calculated as:

$$Z = V / A_L \,. \tag{1}$$

Let P equal mean precipitation in inches (value found in Anonymous 1979), and A_D equal watershed area in square miles. Q is the mean annual stream flow in cubic feet per second. Q is calculated as follows:

$$Q = 0.0312 \cdot P \cdot 1.13 \cdot A_D^{1.03}. \tag{2}$$

Q is then converted from cubic feet per second to cubic meters per year, which is the total lake outflow, or *TLO*. The theoretical water residence time in years, T_W , is calculated as follows:

$$T_W = V / TLO. \tag{3}$$

The euphotic zone depth (EZD) was defined as the depth to which 1% of the subsurface light (photosynthetically available radiation 400–700 nm) penetrates the water column (Schindler 1971). This value is equivalent to the *Y*-intercept, determined by regressing depth against the natural logarithm of the percent sub-surface light. The vertical extinction coefficient (K_d) was calculated as the reciprocal value of the regression slope. The trophogenic zone of a lake, where photosynthetic activity predominates, is defined as the product of EZD and the surface area of the lake.

Conductivities (temperature compensated to 25°) were measured using a Yellow Springs Instrument (YSI) model 32 conductance meter. Turbidities (NTU) were determined using a model DRT-100 laboratory turbidimeter. Water color was determined on filtered lake water by measuring the spectrophotometric absorbance at 400 nm and converting to platinum cobalt (Pt) units using a standard calibration curve (Koenings et al. 1987). Calcium and magnesium concentrations were determined from separate EDTA (0.01 N) titrations after Golterman (1969). Total iron was analyzed by reduction of ferric iron with hydroxylamine after hydrochloric acid digestion using the method of Strickland and Parsons (1972).

Filterable reactive phosphorus (FRP) was determined using the molybdenum-blue method as modified by Eisenreich et al. (1975). Total phosphorus (TP) and total filterable phosphorus (TFP) utilized the same procedure following acid-persulfate digestion. Nitrate (NO_3) plus nitrite (NO_2) were determined as nitrite following cadmium reduction of nitrate, and total ammonia was determined using the phenolhypochlorite procedure described in Stainton et al. (1977). Total Kjeldahl nitrogen (TKN) was determined as total ammonia following sulfuric acid reduction to molybdenum-blue (Stainton et al. 1977), and alkalinities were determined by sulfuric acid (0.02 N) titration to pH 4.5.

Chlorophyll *a* (chl *a*) samples were prepared by filtering a known quantity of lake water through a Whatman 47 mm GF/F glass fiber filter using a vacuum pressure of <15 mm of Hg. Prior to the completion of filtration ~ 2 ml of 1 N magnesium carbonate was added to the filter. Filters were stored frozen in plexiglas petrislides until processed. Chl *a*, corrected for inactive phaeophytin (phaeo *a*), was determined by the direct fluorometric method of Strickland and Parsons (1972) using dilute acid addition (Reimann 1978).

Bosmina and *Daphnia* were identified according to Brooks (1957) and Pennak (1978). Copepod zooplankters were determined after Wilson (1959) and Yeatman (1959). Zooplankters were enumerated from 3 1-ml subsamples collected with a Hensen-Semple pipette and placed in a 1-ml Sedgewick-Rafter counting chamber. The seasonal mean zooplankton densities by species were calculated by dividing the number of plankton estimated per tow by the area (m^2) of the net opening or by the volume (m^3). Average zooplankton body-sizes were determined from measurements of 30 organisms of each species measured to the nearest 0.01 mm along a transect in each of the 1-ml subsamples, using a calibrated ocular micrometer (Koenings et al. 1987). Biomass was determined using live length to dry weight regressions for individual zooplankters. The seasonal mean density and body-size (numbers weighted length) was used to calculate the mean seasonal biomass for each species, which were then summed.

Estimates of yearly phosphorus loading were calculated after Vollenweider (1976). Most Alaskan lakes are oligotrophic, and their productivity is usually limited by the amount of phosphorus (P) available. P-loading is often expressed as an amount of P input to the lake per unit surface area per year, say, mg/m2/yr or kg/km2/yr. The critical P-loading rate (Lc) has been defined by Vollenweider as that phosphorus load that produces a total phosphorus concentration representing a mesotrophic state (i.e., average total-phosphorus concentration in the lake of 10 ug/L (<10 is oligotrophic, 10-20 is mesotrophic, and >20 ug/L is eutrophic). The amount of phosphorous loaded into Gil Lake in the spring is 3.5 µg/l.

To calculate the surface let, $\bar{z}$ equal mean depth in meters, T_w equal mean residence time in years, and Qs equal $\bar{z}/T_w$. Then, let $\hat{P}_C^{SP}$ equal the spring overturn period of total phosphorus (in µg/m^3). For this report, $\hat{P}_C^{SP}$ was the phosphorus concentration present in the samples taken in May. The surface specific phosphorus loading, L_p, (in µg phosphorus/ m^2/year) is calculated as follows:

$$L_p = P_C^{SP} \cdot Qs \cdot (1 + \bar{z} / Qs)\,. \tag{3}$$

The surface critical loading, L_C, in µg phosphorus/m^2/year, is calculated as follows:

$$L_C = 10 \cdot Qs \cdot (1 + \bar{z} / Qs)\,. \tag{4}$$

RESULTS

Physical Characteristics and Morphometry

Gil Lake has a surface area of 40 hectares, or nearly 100 acres, a mean depth of 8 meters (27 feet) and a maximum depth of 28 meters (92 feet; Table 1, Figure 1). The watershed draining into Gil Lake encompasses 773 hectares, or 1,910 acres.

According to the bathymetric map, the lake volume is 1.173 billion cubic feet, or 32.85 million cubic meters. Lake morphometry of Gil Lake indicates that almost 90% of the water volume is contained in the 1 to 10 foot depth stratum (Table 2). Other individual depth strata contain 3.1% or less of the total volume of the lake. The volume development ratio was 0.88, indicating that the lake has deep holes (Wetzel 2000). The shoreline development is 2.66, indicating a convoluted shoreline.

The bathymetric map was developed using sparse data. Too few depth transects were recorded in the field, which did not allow for adequate separation of depth strata and required lots of guesswork in developing the bathymetric map. Therefore, the map and associated morphometric values must be viewed with some skepticism. However, the lack of accuracy in the map does not preclude us from making valid comments concerning the suitability of Gil Lake for enhancement projects.

According to the field researcher, the lake inventory did not discover any suitable spawning habitat in Gil Lake or its inlet streams. The inlet streams are no more than seeps, and there is no shoaling in the lake itself. (Barto, pers. comm.).

Light Regimes and Heating and Cooling Cycles

The average euphotic zone depth (EZD) for Gil Lake was calculated to be 5.2 m during 1997 (Table 3). Also known as the compensation depth, the EZD was at 4.2 m in May of 1997, increased to 7.0 m in August, and decreased to a depth of 4.0 m in September and 3.1 m in October.

The surface temperature in May was 10.7° C in May, and a thermocline had already formed at a depth of about 4 m. The surface temperature increased to 20.1° C in August. In October, the surface temperature had decreased to 7.9° C, and the lake was in the process of becoming isothermal (Table 4).

A stable thermocline became established early in the season at a depth of about 4 m, but the average light compensation depth was 5 meters. This suggests that autotrophic production was not necessarily limited to the epilimnion of the lake, but could also occur in the upper reaches of the hypolimnion.

General Water Quality and Dissolved Gases

Water quality indicators were in the upper intermediate range, compared to coastal Alaskan lakes, and levels were consistent throughout the sampling periods (Barto and Koenings unpublished report). The observed levels indicated little variation relative to sampling periods or depths at the sampling site (Appendix A). Conductivity levels varied from 83 to 90 μmohs/cm (n=6) within the epilimnion and from 103 to 111 μmohs/cm (n=6) within the hypolimnion during the sampling period.

The water column was well oxygenated throughout the water column (Table 5). The dissolved oxygen concentrations in the epilimnion decreased slightly over the summer, then began increasing in September. The amount of oxygen in the hypolimnion decreased faster than in the epilimnion, and the oxygen continued until the lake began to turn over in October.

Alkalinity levels were in the upper intermediate range, relative to coastal Alaskan lakes (Barto and Koenings unpublished report), as mean levels calculated to 42.2 ppm in the epilimnion, and 53.6 ppm in the hypolimnion. Calcium levels remained fairly constant over the study year, ranging from 14.4 to 15.3 ppm in the epilimnion, and 17.9 to 20.3 ppm in the hypolimnion. The mean magnesium levels between epilimnion and hypolimnion were nearly the same, 0.6 ppm and 0.7 ppm, respectively, and ranged from <0.3 ppm to 0.9 ppm in the epilimnion, and 0.5 to 1.1 ppm in the hypolimnion. Iron (36 to 63 ppb), turbidity (mean levels of 0.5 and 0.8 NTU units) and color (22 to 36 Pt units) were as normal for oligotrophic, stained-water coastal lakes in Alaska. The pH levels were slightly basic, ranging from 7.4 to 7.7 in the epilimnion and 7.0 to 7.1 in the hypolimnion.

Nutrient Concentrations and Atom Ratios

Seasonal nutrient concentrations (Appendix A) and cycles are of primary interest because they are taken up by the primary producers in the lake system, and directly affect the conversion of available energy within the lake to rearing fish biomass (Barto and Koenings unpublished report). Alaskan sockeye salmon nursery lakes are predominately oligotrophic, and their productivity is generally limited by the phosphorus concentrations in the water (total phosphorus concentrations are generally 10 to 30 μg/L, or parts per billion for mesotrophic and eutrophic lakes and less than 10 μg/L for oligotrophic lakes; Wetzel 2000). Furthermore, sockeye salmon nursery lakes can receive significant input from the decay of anadromous adult carcasses after spawning. Also important to lake productivity are the concentrations of inorganic nitrogen (ammonium and NO_3 + $NO_{2)}$), reactive silicon, reactive and total phosphorus and the nitrogen:phosphorus ratio.

The seasonal mean values for inorganic nitrogen levels were 40 ppb in the epilimnion and 73 ppb in the hypolimnion. Total nitrogen levels in the epilimnion ranged from 114.3 ppb in June to 209.4 ppb in October. Inorganic and total nitrogen levels in the epilimnion dropped slightly in June and July, spiked upward in August, dropping in September, and spiking again in October. Hypolimnion nitrogen levels spiked upward to 19.8 ppb for inorganic nitrogen and 346 ppb for total nitrogen in September, before dropping to 58 ppb inorganic nitrogen and 174 ppb total nitrogen in October.

The total phosphorus in the epilimnion increased steadily from 2.4 in May to 3.7 ppb in October. The nitrogen:phosphorus atom ratio in the epilimnion ranged from 70:1 in May to 130:1 in September, and averaged 105:1 for the sampling period. Total phosphorus in the hypolimnion spiked upward from 3.8 ppb in August to 19.8 ppb in September. Hypolimnion nitrogen to phosphorus ratios ranged from 40:1 in August to 113:1 in September, and averaged 64:1 during the sampling period.

Mean levels for reactive silicon (Si), required for frustule cell structure formation by diatoms, are within the median range for coastal Alaskan lakes. The level of reactive silicon tended to rise over the season, ranging from 689 ppb in May to 955 ppb in October in the epilimnion. Reactive silicon levels in the hypolimnion were higher, ranging from 838 ppb in May to 1225 ppb in October.

Algal Biomass (Chlorophyll a)

The mean concentrations of chlorophyll *a* in 1997 were 0.51 ppb at the 1 m depth, 0.63 ppb at the mid-euphotic depth, and 1.01 ppb at the compensation depth (Appendix A). Chlorophyll *a* concentrations at all sampled depths were highest in May, had similar lower concentrations in July and August, and increased in September and October. Phaeophytin *a* levels showed similar trends. Chlorophyll *a* concentrations were within levels expected for stained-water systems within Alaska (Barto and Cook 1996).

Zooplankton Density, Body-size, and Biomass

The zooplankton community within Gil Lake is comprised of four species of cladocerans and two species of copepods (Appendix B). The most common cladoceran was *Bosmina* sp. The copepod community consisted of Cyclops sp. and *Epischura sp*.

As a group, cladocerans comprised about 30% of the total macrozooplankton density. *Bosmina* sp. was numerically dominant. Density of *Bosmina* in the samples ranged from $5,944/m^2$ to $38,445/m^2$, and averaged $16,150/m^2$. *Daphnia longiremis*, *Daphnia* sp., and *Holopedium* sp. were the other cladocerans found in the samples. Densities for *Daphnia longiremis* ranged from 11,207/m in May to 713/m in October, and averaged 4,390/m over the season. *Daphnia* sp. densities ranged from 13,178/m in July to 577/m in October, averaging 2,955/m over the season. *Holopedium* sp. was present in 8 of the 12 samples collected over the sampling period. When present, densities of *Holopedium* sp. range from too few to estimate, to 6,521/m. In general, the highest densities of cladoceran occurred in July. Mean length ranged from 0.39 mm for *Bosmina* to 0.98 mm for *Daphnia* sp. In general, mean length increased over the sampling period.

Copepods comprised about 70% of the total macrozooplankton density. The dominant copepod was *Cyclops* sp., and *Epischura* sp. was present in much smaller numbers. Densities of *Cyclops* sp. ranged from 104,772/m in May to 21,328/m in October. Densities of *Epischura* sp. ranged from 509/m to 16,709/m. In contrast to *Cyclops* sp., whose numbers started high in the spring and tended to decrease over the summer and fall, numbers of *Epischura* sp. were initially low, peaked in July, and decreased as the season progressed.

The mean total weighted macrozooplankton biomass was 192.5 mg/m^2. *Cyclops* sp. comprised the 42% of the biomass. *Epischura* sp., due to large mean body size, comprised 29% of the biomass. The numerically dominant *Bosmina* sp. contributed 12% to mean weighted biomass. *Daphnia longiremis*, *Daphnia* sp., and *Holopedium* sp. comprised 6%, 4%, and 5% of the biomass, respectively.

In comparison to other sockeye salmon lake systems in Southeast Alaska, mean seasonal zooplankton densities and biomass for Gil Lake are close to median values (Table 6). In comparison to barriered lake systems, macrozooplankton densities for Gil Lake also tend to be near the median. However, the biomass estimates are among the lowest recorded in the barriered systems studied (Table 7). This suggests that although the zooplankton densities are in the mid-range, the size of the zooplankton is small compared to other lakes.

Nutrient Loading Characteristics

The productive capacity of lakes is determined by edaphic, morphometric, and climatic factors linked to the cycling of carbon, nitrogen, phosphorus, and silica within the lake environment (Barto and Cook, 1996). Drainage basins, and possibly returning adult salmon, import or load nutrients into their lakes and streams. Availability of nutrients critical to aquatic primary producers is also dependent upon lake morphometry and water retention (Wetzel 2000). Productivity of Alaskan lakes is usually limited by the low concentrations of phosphorus. Gil Lake's surface specific loading and surface critical loading are orders of magnitude lower than other lakes studied, because of low mean depth and low flushing (Table 8). The spring phosphorus loading value indicates that Gil Lake has about 35% of the phosphorus it needs to become a mesotrophic lake.

DISCUSSION

The major biological limitations to developing a sockeye salmon enhancement project at Gil Lake are the lack of spawning sites and the low zooplankton biomass densities. The lack of spawning sites would require the lake to be stocked annually with no prospect of developing a self-sustaining run in the future.

The increased predation pressure on the already low zooplankton standing stock would most likely require annual lake fertilization, in addition to the stocking of fry or incubation of eggs. The quality of the zooplankton food may also be less than other systems. Although 30% of the zooplankton species were cladocerans, the preferred of sockeye salmon fry, their small mean size suggests that sockeye salmon fry would switch to the larger less desirable copepods. Furthermore, Gil Lake is small and does not provide a substantial rearing area for sockeye salmon fry.

Information on trophic level interactions and other food web dynamics are also lacking for the Gil Lake system. Several studies have shown that predators are capable of reducing sockeye salmon fry numbers to low levels (Cartwright et al. 1998, Beauchamp 1994, Beauchamp et al. 1995). Competition between species can also suppress sockeye salmon production. Threespine sticklebacks (*Gasterosteus aculeatus*), a common planktivore in Southeast Alaskan lakes, could limit production of sockeye salmon (O'Neill and Hyatt 1987). Predator surveys on Gil Lake have thus far been cursory, and the presence or absence of stickleback in Gil Lake is not known. Food web structures are complex and can determine the success or failure of a sockeye salmon enhancement project (Mazumder and Edmundson 2002).

In summary, to establish a sockeye salmon run into Gil Lake, fish would have to be artificially incubated and stocked into a small lake with limited rearing capacity. Even if the artificial incubation were to work, trophic level interactions and other food web dynamics could undermine the success of this enhancement project. The lead agency would need to monitor food web changes, and make necessary changes in the lake system to maintain the balance between the introduced sockeye salmon fry, their predators and competitors, and their food resource. The task of maintaining this balance is enormously complex and will require extensive monitoring and a large commitment of resources.

LITERATURE CITED

Anonymous. 1979. Water resources atlas for USDA Forest Service, Region 10, Juneau, Alaska. Prepared by Ott Water Engineers, Inc., Redding, California.

Barto, D. L., and B. T. Cook. 1996. A limnology and fisheries investigation of Kanalku Lake. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division Regional Information Report No. 5J96-18.

Beauchamp, D. A. 1994. The spatial and temporal of piscivory: implications for food web stability and the transparency of Lake Washington. Lake Reservoir Management 9:151– 154.

Beauchamp, D. A., M. G. LaRiviere, and G. L. Thomas. 1995. Evaluation of competition and predation as limits to juvenile kokanee and sockeye salmon production Lake Ozette, Washington. N. Am. J. Fish. Manage. 15: 193–207.

Brooks, J. L. 1957. The systematics of North American *Daphnia*. Memoirs of the Connecticut Academy of Arts and Sciences, 13:1–180.

Burgner, R. L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). Pages 1–117 *in* C Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, Canada.

Cartwright, M. A., D. A. Beauchamp, and M. Bryant. 1998. Quantifying cutthroat trout (*Oncorhynchus clarki*) predation on sockeye salmon (*O. nerka*) fry using a bioenergetic approach. Can. J. Fish. Aquat. Sci. 55:1285–1295.

Eisenreich, S. J., R. T. Bannerman, and E. D. Armstrong. 1975. A simplified phosphorus analysis technique. Environmental Letters 9:43–53.

Golterman, H. L. 1970 Methods for chemical analysis of freshwater. Blackwell Scientific Publications, IBP Handbook 8, Oxford.

Hutchinson, G. E. 1957. A treatise on limnology, volume 1, part 1. John Wiley and Sons, New York.

Koenings, J. P., J. A. Edmundson, G. B. Kyle, and J. M. Edmundson. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, Fisheries Rehabilitation, Enhancement, and Development Division, FRED Report Series 71, Juneau.

Mazumder, A. and J. A. Edmundson. 2002. Impact of fertilization and stocking on trophic interactions and growth of juvenile sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 59:1361-1373.

Pennak, R. W. 1978. Freshwater invertebrates of the United States, 2nd edition. John Wiley and Sons, NY.

Reimann, B. 1978. Carotenoid interference in the spectrophotometric determination of Chlorophyll degradation products from natural populations of phytoplankton. Limnology and Oceanography 23:1059–1066,

Schindler, D. W. 1971. Light, temperature and oxygen regimes in selected lakes in the experimental lakes area, northwestern Ontario. Journal of the Fisheries Research Board of Canada 28:157–169.

Stainton, M. P., M. J. Capel, and F. A. J. Armstrong. 1977. The chemical analysis of freshwater, 2nd edition. Canadian Special Publications, 25.

Strickland, J. D. H. and T. R. Parsons. 1972. A practical handbook of seawater analysis, 2nd edition. Fisheries Research Board of Canada Bulletin 167.

LITERATURE CITED (Continued)

Vollenweider, R. A. 1976. Advances in defining control loading levels for phosphorous in lake eutrophication. Memoirs of the Institute of International Idrobiology. 33:53–83.

Wetzel, R. G. 2000. Limnology lake and river ecosystems, 3rd ed. Academic Press, San Diego, CA.

Wilson, M. S. 1959. Calanoida. Pages 738–794 *in* W. T. Edmundson [*ed.*]. Fresh-water biology, 2nd edition. John Wiley and Sons, New York.

Yeatman, H. C. 1959. Cyclopoida. Pages 795–815 *in* W. T. Edmundson [*ed.*]. Fresh-water biology, 2nd edition. John Wiley and Sons, New York.

Table 1. Physical characteristics of Gil Lake.

Lake Area: 40.3 hectares (99.48 acres)	Watershed Area: (773 hectares) (1,910 acres)
Maximum Depth: 28 meters (92 feet)	Mean Depth: 8.24 meters (27 feet)
Lake Volume: 32,852,545 cubic meters (1,173,305,182 cubic feet)	Volume Development: 0.88
Shoreline Length: 5,984 meters (19,632 feet)	Shoreline Development: 2.66
Lake Elevation: 77 meters (253 feet)	

Table 2. Morphometry of Gil Lake.

Area by Depth Zone

Depth Zone (feet)	Area (sq. Meters)	Area (sq. Feet)	Percent of Surface Area
0	403,042	4,333,780	100%
10	355,758	3,825,351	88.3%
20	308,611	3,318,402	76.6%
30	251,532	2,704,648	62.4%
40	205,418	2,208,801	51.0%
50	158,219	1,701,282	39.3%
60	91,822	987,332	22.8%
70	30,510	328,061	7.6%
80	6,201	66,681	1.5%
90	46	493	0.0%
Lake Surface Area:	41.3 hectares	99.5 acres	

Volume by Depth Zone

Depth Zone (feet)	Volume (Cubic Meters)	Volume (Cubic Feet)	Percent of Total Volume
0-10	29,141,996	1,040,785,557	88.7%
10-20	1,002,563	35,805,836	3.1%
20-30	845,773	30,206,189	2.6%
30-40	687,784	24,563,730	2.1%
40-50	546,114	19,504,081	1.7%
50-60	396,399	14,157,124	1.2%
60-70	178,898	6,389,211	0.5%
70-80	46,529	1,661,741	0.1%
80-90	6,479	231,384	0.0%
90+	9	329	0.0%
Total Lake Volume	32,852,545	1,173,305,182	100.0%

Table 3. Light penetration data obtained from Gil Lake, indicating the euphotic zone depth, and vertical extinction coefficient (Kd), and Secchi disk depth by sample date, 1997.

	Site 1	
Date	Euphotic Zone Depth (m)	Vertical Extinction Coefficient (/m)
05/12	4.2	1.03
06/17	5.7	0.78
07/22	6.8	0.64
08/18	7.0	0.64
09/17	4.0	1.18
10/13	3.1	1.33
Mean	5.1	0.9

Table 4. Water temperature (°C) by depth at Gil Lake during 1997.

	Sampling Date					
Depth (m)	12-May	17-Jun	22-Jul	18-Aug	17-Sep	13-Oct
Surface	10.7	16.9	17.4	20.1	15.4	7.9
1	10.1	16.8	17.1	20	15.4	7.9
2	9.8	16.2	17	20	15.2	7.9
3	8	14.8	16.3	19.2	15.2	7.8
4	6.3	9	13	15	15	7.8
5	5	6	9.9	12	12.1	7.8
6	4.2	5	6	9.9	10	7.6
7	4.1	4.8	5	7.9	7.8	7.5
8	4	4.5	4.8	6.4	6.1	7
9	4	4.3	4.2	5.2	5.8	5.6
10	4	4.3	4	5	5.4	5.4
15	4	4	3.9	4.1	4	4

Table 5. Dissolved oxygen concentrations (mg/l) by depth at Gil Lake during 1997.

	Sampling Date					
Depth (m)	12-May	17-Jun	22-Jul	18-Aug	17-Sep	13-Oct
Surface		9.0	9.4	9.3	10.2	10.2
1	11.5	9.6	9.4	9.3	10.2	10.2
2	11.4	9.8	9.4	9.2	10.4	10.2
3	11.2	11	9.3	8.9	10.4	10.2
4	11	11.2	9.2	8.9	10.4	10.2
5	10.8	10.8	9.3	8	8.4	10.2
6	10.5	9.3	8.6	7.1	8	10.1
7	10.2	8.4	8.4		7.4	10
8	9.8	8.6	8	7	7.8	7.8
9	9.8	8.4	7.9	7	7.2	6.8
10	9.4	8.4	7.4	7.2	7.2	6.4
15	9.4	8.4	7	7.6	6.6	5.8

Table 6. Comparison of seasonal mean (April–November) macrozooplankton density and biomass for Gil Lake to clear, stained (*) and glacial (**) sockeye salmon nursery lakes throughout Southeast Alaska.[a]

Lake	Years Sampled	Biomass (mg/m^2)	Density ($No./m^2$)
Politofski	80	39	17,967
Falls *	81-82	54	21,587
Speel *	89-92	58	64,380
Falls *	**83-85**	**59**	**25,847**
Benzemen	81	71	50,067
Crescent	80-81,87-92	74	46,598
Virginia	89-90	79	38,102
Redoubt *	80-83	90	74,363
Situk *	87-89	95	104,732
Mountain	87,88	115	111,711
Chilkoot **	87-91	126	72,704
Redoubt *	**84-87,90-94**	**130**	**105,867**
Gil *	97	193	83,926
McDonald *	80-81	219	79,345
Kook *	92,94,95	246	76,218
Sitkoh *	92	291	108,877
Virginia	**91-92**	**322**	**161,498**
McDonald *	**82-94**	**323**	**95,776**
Kanalku *	95	372	102,427
Auke *	86,89-94	424	146,849
Hugh Smith *	**80-84**	**530**	**316,363**
Hugh Smith *	85-87,93,94	573	291,029
Chilkat	87-91,94	1,333	567,899
Tumakof *	80	1,519	614,559

[a] Bold type indicates years of fertilizer application to the lake.

Table 7. Comparison of seasonal mean (May–October) macro-zooplankton density and biomass for Gil Lake, to barriered systems and salmon fry stocking projects in lakes throughout Southeast Alaska.[a]

				Macrozooplankton (Number-Weighted Seasonal Means)		
Lake	Years Sampled	Resident Fish	Salmon fry Stocked	Biomass (mg/m^2)	Density ($No./m^2$)	Percent Community Comp (Copepod/Cladocera)
Gil	97	Dolly Varden		193	83,296	72/28
Deer	84	Rainbow		209	39,616	59/41
Sweetheart	**90,91,92,93**		**sockeye**	**210**	**92,585**	**93/7**
Eliza	86		chinook	264	78,857	95/5
Turner	85,86,89	Cutthroat, Kokanee		281	137,844	76/24
Sea Lion Cove	**82,83**		**coho**	**290**	**96,602**	**63/37**
Sweetheart	89	Rainbow, Dolly Varden		335	114,613	89/11
Deer	**85**		**coho**	**338**	**54,477**	**74/26**
Eliza	85	Dolly Varden		367	111,500	80/20
Sea Lion Cove	80,81	none		397	155,277	44/56

[a] Bold type indicates years of salmon fry stocking to the lake.

Table 8. Comparison of the spring phosphorous loading characteristics for Gil Lake to barriered lakes throughout Southeast Alaska.

Lake	Sampling Year(s)	Mean Depth (Z) (Z)	Water Residence Time (Tw)	Spring Total Phosphorous (TPsp)	Surface Specific Loading (Lp)	Surface Critical Loading (Lc)	Spring Phosphorous Loading (Lp/Lc)
		(m)	(yr)	(ug/l)	(mg P/m2/yr)	(mg P/m2/yr)	(%)
Sea Lion Cove	83	4.3	0.25	3.2	83	258	0.32
Banner	83,84	51.2	0.79	1.9	233	1,224	0.19
Lower Rostislaf	84,88	45.5	0.65	1.8	228	1,264	0.18
Osprey	83,84,85	59.7	1.40	2.0	186	931	0.2
Deer	84,85,88-2000	110.0	3.59	2.1	186	887	0.21
Sweetheart	90-94	75.0	1.09	2.4	338	1,406	0.24
Turner	85-87	123.0	2.95	3.2	363	1,133	0.32
Farragut	85,86,92-94	67.0	1.27	13.2	1,481	1,122	1.32
Gil	97	8.2	2.39	3.5	31	88	0.35

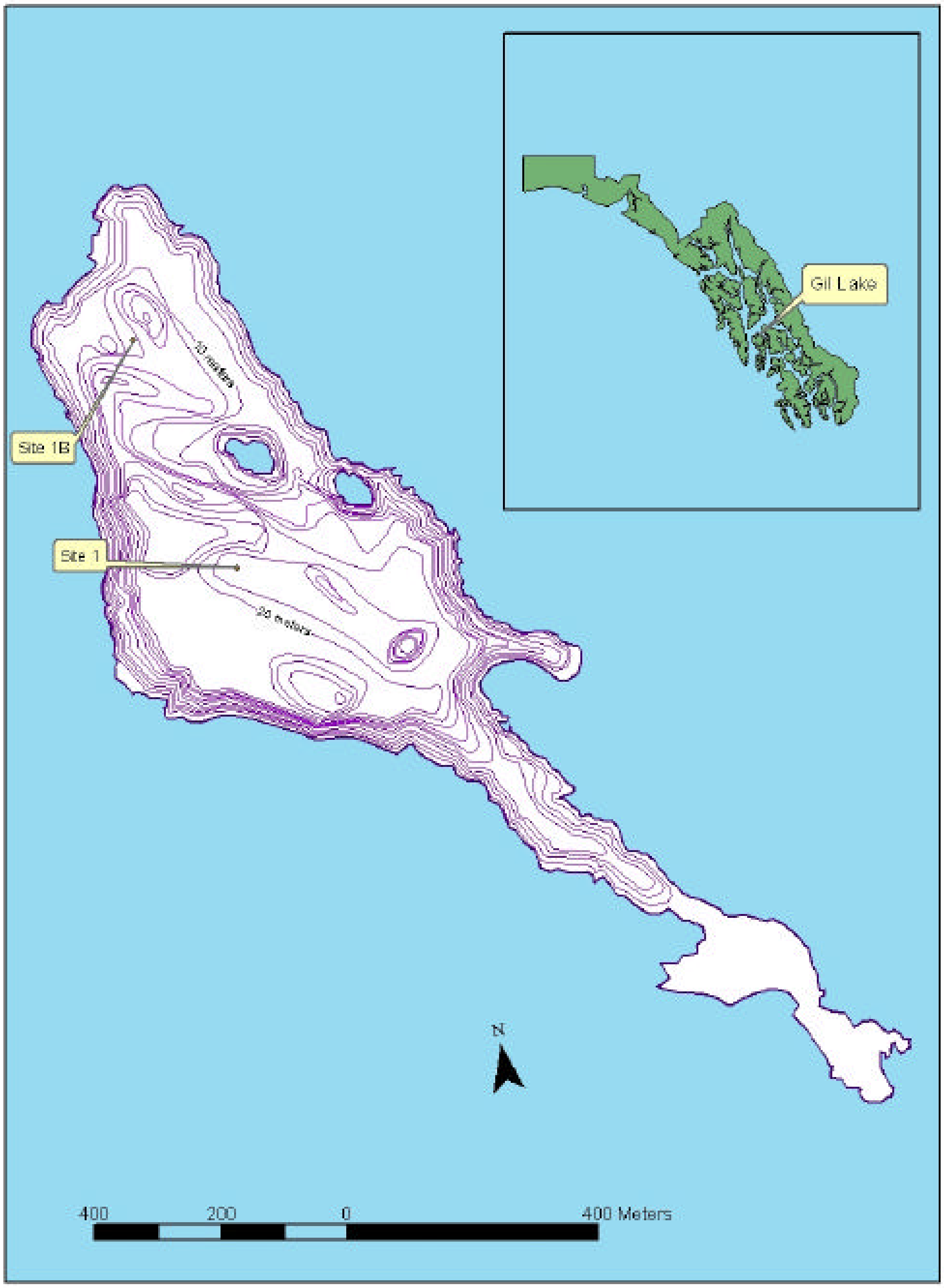

Figure 1. Bathymetric Map of Gil Lake, with inset of Southeast Alaska. Depth contours are in 2-meter increments. Sites 1 and 1B are limnological sampling stations.

The Alaska Department of Fish and Game administers all programs and activities free from discrimination on the basis of sex, color, race, religion, national origin, age, marital status, pregnancy, parenthood, or disability. For information on alternative formats available for this and other department publications, contact the department ADA Coordinator at (voice) 907-465-4120, (telecommunication device for the deaf) 1-800-478-3648, or fax 907-465-6078. Any person who believes she/he has been discriminated against should write to: ADF&G, PO Box 25526, Juneau, AK 99802-5526, or OEO, U.S. Department of the Interior, Washington, DC 20240.